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LANL’s Development of Schedule Contingency Based on Probabilistic Risk Results

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Introduction

The need for budget reserve in project planning is widely recognized, but the need for a corresponding schedule reserve is generally not as universally acknowledged. Los Alamos National Laboratory (LANL) performs probabilistic project risk analyses for all major projects; the question has become how to more fully use the results of the schedule analyses to establish a schedule reserve. Before the use of quantitative project risk analysis, milestones were based on the initial point estimate with float time as the only time reserved for delays. With this practice, the set of tasks that have duration reserve is limited. In particular, critical path tasks, which do not have associated float, do not have reserve schedule time to use for delays. For other tasks, float was used on a “first-come, first-served” basis without allocation to other tasks. Thus, it was not possible to systematically allocate schedule reserve to project tasks.

Project Risk Assessment Approach

Almost every large project is subject to schedule delays, and furthermore schedule delays often translate into cost overruns. A project risk assessment is performed to identify and mitigate potential contributors to cost increases and schedule delays. The assessment is used to establish contingency or reserve to contain potential overruns, both dollars and days. The focus of this paper is the use of the schedule risk assessment to establish the contingency.

There are many different approaches to assessing the potential for schedule uncertainty. They may be as simple as doubling the amount of time necessary to complete the project or using another simple algorithm. Linear programming and decision-tree analysis also may be used (Wendling, 1999). LANL uses Monte Carlo or random sampling simulations for project risk analysis of large projects (Kindinger, 1999). Monte Carlo simulations are used because they provide a way to assess each task individually and normal distributions do not have to be assumed. Furthermore, the critical path is not static during the simulations, and more than one critical path is examined. The simulation allows opportunities to perform a sensitivity analysis, and it is easy to identify the confidence interval of the schedule.

Project Risk Assessment Methodology Used at LANL

A general understanding of the project risk assessment methodology aids in the discussion of the application of the project risk analysis to determine contingency. At LANL, the project risk assessment is performed in two basic steps: a qualitative analysis followed by a quantitative analysis. The identification of potential risks requires the systematic review of the entire project during which the technical, cost, and schedule risks are evaluated using project-specific risk rating criteria.

The qualitative assessments are then translated into numerical values that are used to develop the input data distributions, which in turn are fed into the quantitative model.

Project Risks Associated with Schedule Delays

Before reviewing a task, the analyst defines the potential risks based on the features of the task. Schedule, cost, and technical risks cannot be considered independently, and cost and technical risks often influence the schedule risks. Some examples of risk factors are presented in Table 1.

Examples of Schedule Risks	Examples of Cost Risks	Examples of Technical Risks
Area/facility availability Personnel availability Productivity uncertainty Adverse environmental conditions Equipment/materials availability	Labor rate uncertainty Equipment/material cost uncertainty Escalation sensitivity Estimate completeness	Technology maturity Rework potential Infrastructure needs Design/analysis data availability Methods maturity Licensing/ approval severity

Exhibit 1. Examples of Risk Criteria.

Risk factor rating criteria are used to guide the qualitative analysis of each task, which results in a risk rating of "high," "medium," or "low" for each task. The qualitative results and any specialized quantitative data are used to develop the uncertainty distributions for each task in the project risk model. Simulation models using tools such as Crystal Ball produce cumulative probability distribution functions (PDFs) that describe the confidence level given to the achievement of the project performance. The PDFs are used in developing the contingency recommendations for the project and each element of the task. Below is an example of schedule risk output for a LANL project.

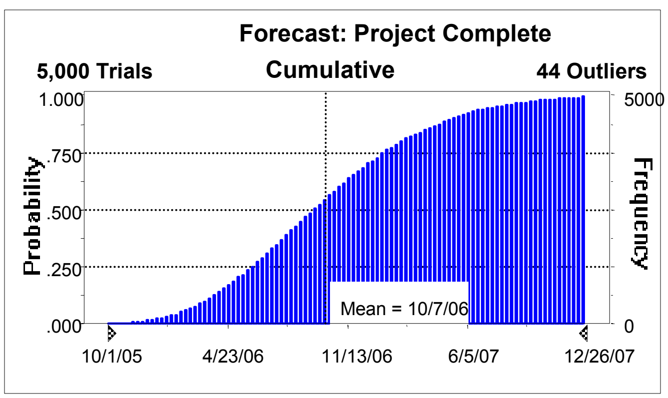

Exhibit 2. Example of Results from a LANL Project.

Contingency Analysis

Contingency reserve is defined in **A Guide to Project Management Body of Knowledge** (1996) as "A separately planned quantity used to allow for future situations which may be planned for only in part (sometimes called the "known unknowns"). For example, rework is certain, the amount of rework is not. Contingency reserve may involve cost, schedule, or both. Contingency reserves are intended to reduce the impact of missing cost or schedule objectives. Contingency reserves are normally included in the project's cost and schedule baselines." Because one of the purposes of the contingency analysis is to recommend the amount of contingency, the contingency is not included in the point estimate at LANL. Furthermore, contingency reserve at LANL is often divided in two parts, LANL Management Reserve (MR) and DOE Contingency (Kindinger, 2000).

Determining Schedule Contingency

Two of the challenges associated with the allocation of schedule contingency (SC) are the existence of parallel paths and the ability to ensure that contingency is available for later tasks. The existence of parallel paths is addressed using the traditional methods of assigning float based on the durations of the parallel tasks. The second question of ensuring that contingency is available for later tasks is addressed by allocating the SC based on the risk of the task and the point-estimate duration of the task.

To develop the allocation of contingency, three cases are use to step through the process. Case I uses only the point estimates to determine the SC; in other words, the float is the SC. Case II builds on Case I and uses the mean to develop the contingency. Because the contingency is based on the mean values, the contingency can be calculated directly for each task as the difference between the point-estimate duration and mean value of the risk analysis distribution. The use of the mean is recommended by Wendling (1999) to develop contingency, and the analysis could be considered complete after this step. However, for the LANL project, the contingency is also calculated at the 85th percentile confidence level to allow management at a higher level of confidence. Case III develops the 85th confidence value from the Monte Carlo simulation. As Kindinger (1999) explains, the individual independent distributions cannot be simply added to obtain the corresponding point-value from the probabilistic sum of the distributions. Thus, the task-level contingencies must be prorated to be proportional to with their contribution to the project total duration.

All of the cases are based on the same data in which the means and 85th percentile values are derived from a Monte Carlo simulation assessment. A simple project of six tasks with the relationships shown in Figure 2 is used in all three examples. For the sake of the examples, it is assumed that all tasks have finish-to-start relationships with their predecessors. The critical path identified in the point estimate is Path A, which consists of Tasks 1 through 4, each with point-estimate duration of 100 days. Path B is composed of Tasks 5 and 6, each with a point estimate duration of 50 days. In the examples, the sum of the duration of Tasks 5 and 6 is less than the sum of the duration of Tasks 2 and 3. This allows the float for Path B to be calculated using the differences between the two sums. The point-estimate durations do not include contingency.

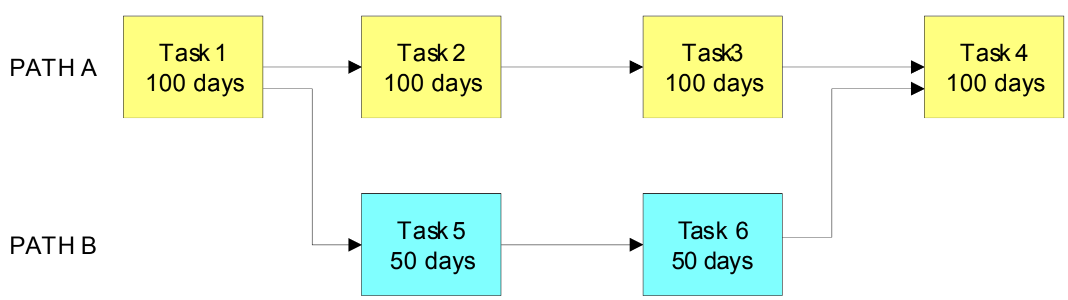

Exhibit 3. Flow Diagram of a Simple Project.

	Point Estimate (PE)	Mean (M)	Simulation Results 85% (SR)
Path A	**400**	**530**	**560**
Task 1	100	120	125
Task 2	100	140	150
Task 3	100	150	175
Task 4	100	120	125
Path B	**100**	**135**	**150**
Task 5	50	75	89
Task 6	50	60	64

Exhibit 4. Results of the Simulation.

Case I: Point Estimate

If a schedule risk assessment is not performed, the schedule contingency is based solely on the point estimate baseline. The only time available for the allocation of contingency is the float time. Thus, critical path elements do not any available contingency.

SC = Allocated Float (AF)
D = Duration = Point Estimate (PE) + AF

Path A
Because Path A is the critical path, the float for critical path tasks is 0; therefore, $SC_{1-4} = 0$.

Task	SC	Duration
Task 1	0	100
Task 2	0	100
Task 3	0	100
Task 4	0	100

Exhibit 5. Case I: Path A Point Estimate, SC, and Duration.

Path B
For large multi-tasked schedules the calculation of the float is complex, however, this paper will use a simplified float calculation. The available float for Path B is the difference between the maximum allowable duration (durations of Tasks 2 and 3) and the point estimate duration (durations of Tasks 5 and 6.)

$$\text{PE Path B} = PE_{\text{Path B}} = PE_{\text{Task 5}} + PE_{\text{Task 6}} = 50 + 50 = 100$$
$$\text{AF Path B} = (D_{\text{Task 2}} + D_{\text{Task 3}}) - PE_{\text{Path B}} = 200 - 100 = 100$$

The available float along Path B could be allocated between Tasks 5 and 6 in different ways. One approach would be to start the tasks as early as possible, this effectively grants the entire available float to Task 6. Another common approach is to start the tasks as late as possible, effectively granting all of the available float to Task 5. Finally, as illustrated below, the available float for Path B could be proportionally divided between Tasks 5 and 6 based on their durations.

$$.AF_{\text{Task}} = (PE_{\text{Task}}/PE_{\text{Path}}) * AF_{\text{Path}}$$
$$SC = AF_{\text{Task}} = (PE_{\text{Task}}/PE_{\text{Path}}) * AF_{\text{Path}}$$

Task	SC	Duration
Task 5	50/100 * 100 = 50	100
Task 6	50/100 * 100 = 50	100

Exhibit 6. Case I: Path B Point Estimate, SC, and Duration.

Case II: Mean

In the second case, the mean from the Monte Carlo assessment is used to determine the contingency. The central limit theorem dictates that the mean of the entire path is the sum of the means of each task. The total schedule contingency for each task now has two components. First, there is the calculated uncertainty in the task duration, and second, any available float along the path to which the task belongs.

$$SC = (M\text{-}PE) + AF$$
$$D = SC + PE$$

Path A
Because Path A is the critical path, the allocated float is 0, and the SC may be computed directly as the difference between the mean and the point estimate. Furthermore, the task-level duration is the mean duration of the task.

Task	SC	Duration
Task 1	120 -100 = 20	100 + 20 =120
Task 2	140 -100 = 40	100 + 40 = 140
Task 3	150 -100 = 50	100 + 50 = 150
Task 4	120 -100 = 20	100 + 20 = 120

Exhibit 7. Case II: Path A Point Estimate, SC, and Duration.

Path B
The total Path B float is calculated using the same algorithm as Case I; the float is the difference between the duration of the sub-path of Tasks 2 and 3 and the duration of Path B. The durations are based on the mean value durations.

$$AF_{Path\ B} = (D_{Task\ 2} + D_{Task\ 3}) - (M_{Path\ B}) = (140 + 150) - 135 = 155$$

As in Case I, the total available float can be distributed using several approaches. Note from the following example that by using the mean values of the task durations in the proportional approach, a risk-based allocation of the available float between Tasks 5 and 6 is obtained automatically. The SC is computed at the task level and the duration of the task is determined by adding the SC to the PE duration.

$$AF_{Task} = (M_{Task} / M_{Path\ B})^{*}\ AF_{Path}$$
$$SC_{Task} = (M_{Task} - PE_{Task}) + AF_{Task} = (M_{Task} - PE_{Task}) + (M_{Task} / M_{Path\ B})^{*}\ AF_{Path}$$

Task	SC	Duration
Task 5	(75-50)+(75/135)*155= 111	50+111=161
Task 6	(60-50)+(75/135)*155= 79	50+79=129

Exhibit 8. Case II: Path B Point Estimate, SC, and Duration.

Case III: 85th Percentile Confidence Level

This case illustrates how a confidence level higher than the mean can be used in managing the project. Except at the mean, the deterministic sum and probabilistic sums are not equal. The sum of the task-level durations must be equal to the duration of the path. Therefore, each task must receive a prorated value of the entire path. The prorated value is proportional to the task's 85th percentile duration. The following formula is used to determine the prorated value.

$$TPC = \frac{Task85\%}{\sum Task85\%} \times PTC$$

TPC = task prorated contingency = PR85
PTC = path total contingency = SR85

Based on the Monte Carlo risk assessment above,

for Path A, $\Sigma 85\% = 125+150+175+125 = 575$.

for Path B, $\Sigma 85\% = 89+64= 153$.

The table below shows the calculation of the prorated 85% values. It should be noted that the sum of the simulation durations of the tasks is greater than the path duration, but the sum of the durations of the prorated tasks is equal to the duration of the path.

	Simulation Results 85% (SR85)	**Prorated 85% (PR85)**
Path A	**560**	**560**
Task 1	125	(125/575) * 560 = 122
Task 2	150	(150/575) * 560 = 146
Task 3	175	(175/575) * 560 = 170
Task 4	125	(125/575) * 560 = 122
Path B	**150**	**150**
Task 5	89	(89/153) * 150 = 87
Task 6	64	(64/153) * 150 = 63

Exhibit 9. Case III 85th Percentile and 85th Prorated Percentile.

The SC is based on the prorated 85th percentile value for each task.

SC = (PR85-PE) + AF
D = PE + SC

Path A
As in Case I and Case II, because A is the critical path the available float is 0, thus, the duration is the prorated 85th percentile value.

Task	SC	Duration
Task 1	(122 -100) +0 = 22	100 + 22 = 122
Task 2	(146 -100) +0 = 46	100 + 22 = 146
Task 3	(170 -100) +0 = 70	100 + 22 = 170
Task 4	(122 -100) +0 = 22	100 + 22 = 122

Exhibit 10. Case III: Path A SC and Duration.

Path B
As in Cases I and II, the total available float for Path B is calculated as the difference between the prorated 85th percentile duration of the sub-path formed by Tasks 2 and 3 and the 85th percentile duration of Path B.

$$AF_{\text{Path B}} = (D_{\text{Task 2}} + D_{\text{Task 3}}) - (SR_{\text{Path B}}) = (146 +170) - 150 = 166$$

Again using the proportional approach for dividing the available float between Task 5 and Task 6, their SCs are calculated using the same algorithms as Case I and Case II.

$$AF_{\text{Task}} = (PR85_{\text{Task}} / SR_{\text{Path B}})* AF_{\text{Path}}$$

$$SC_{Task} = (PR85_{Task} - PE_{Task}) + AF_{Task} = (PR85_{Task} - PE_{Task}) + (PR85_{Task} / SR_{Path\ B})* AF_{Path}$$

Task	SC	Duration
Task 5	(87 - 50)+(87/150)*166 = 133	50+133 = 183
Task 6	(63 - 50)+ (63/150)*166 = 83	50+83 = 133

Exhibit 11. Case III: Path B SC and Duration.

Summary

The following table summarizes the results of the three example cases for the calculation and allocation of schedule contingency to the tasks of the simple project network. On the table PE is the point estimate, AF is the available float, Cont is the contingency, and TD is the total duration.

		Case I			Case II			Case III		
	PE	**AF**	**Cont**	**TD**	**AF**	**Cont**	**TD**	**AF**	**Cont**	**TD**
Path A	**400**	**0**	**0**	**400**	**0**	**130**	**530**	**0**	**160**	**560**
Task 1	100	0	0	100	0	20	120	0	22	122
Task 2	100	0	0	100	0	40	140	0	46	146
Task 3	100	0	0	100	0	50	150	0	70	170
Task 4	100	0	0	100	0	20	120	0	22	122
Path B	**100**	**100**	0	**200**	**155**	**35**	**190**	**166**	**50**	**316**
Task 5	50	50	0	100	86	25	111	96	37	183
Task 6	50	50	0	100	69	10	79	70	13	133

Exhibit 12. Summary.

Conclusions

The teaming of Monte Carlo simulation assessments and a prorating algorithm for schedule contingency, provides a means to determine a recommend a contingency level for not only the entire project, but also for the tasks of the project. The contingency calculations and allocations approach illustrated in this paper provide a risk-based determination of contingency for critical path tasks and a risk-based allocation of available float to non-critical tasks. This provides the project manager with a means of evaluating the progress of the project tasks, and away to reasonably establish milestones for the project tasks.

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